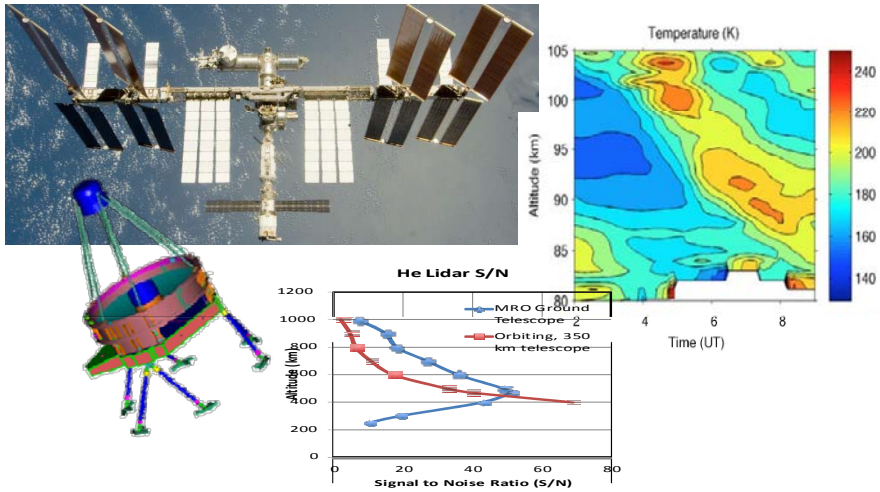
Lidar for the Earth's thermosphere using Large Space Optics on the International Space Station

Groundbreaking Heliophysics science within a modest cost envelope

Idea

- Fly the new Large Space Optics mirror on the International Space Station as part of an advanced lidar facility for upper atmosphere research
- Groundbreaking discoveries will result from global coverage of a large altitude range (30-800 km)
- Implementation will be low-cost due to prior existence of major components of mission
  - ISS
  - Large Space Optics



Relevance to NASA

- The upper atmosphere is a major research target for Heliophysics
- Understanding the dynamics of atmospheres is a fundamental research area
- The upper atmosphere is societally-important
  - Orbit determination
  - Re-entry prediction

Areas in need of study

- Identification of specific science targets in the upper atmosphere
- Trade study to identify the most promising and fruitful atmospheric targets
- Laser capability study
- Detector capability study
- Accommodation on and transportation to the ISS

Lidar for the Earth's thermosphere using Large Space Optics on the International Space Station: Groundbreaking Heliophysics science within a modest cost envelope

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Lidar has proven to be an extremely useful tool for exploring and understanding the Earth's upper atmosphere. The technology has evolved such that routine measurements are now performed to understand the dynamics of the upper atmosphere between 80 and 105 km altitude using sodium lidar. These ground-based instruments return excellent measurements of temperature and density that allow characterization and visualization of structures that are difficult to obtain in other ways, but have proven very important in the Heliophysics goal to understand the upper atmosphere. Fig. 1 displays an example of the measurements that are routinely made at atmospheric observatories. A few facilities even are capable of providing wind information by steering the mirror used to collect the lidar signal.

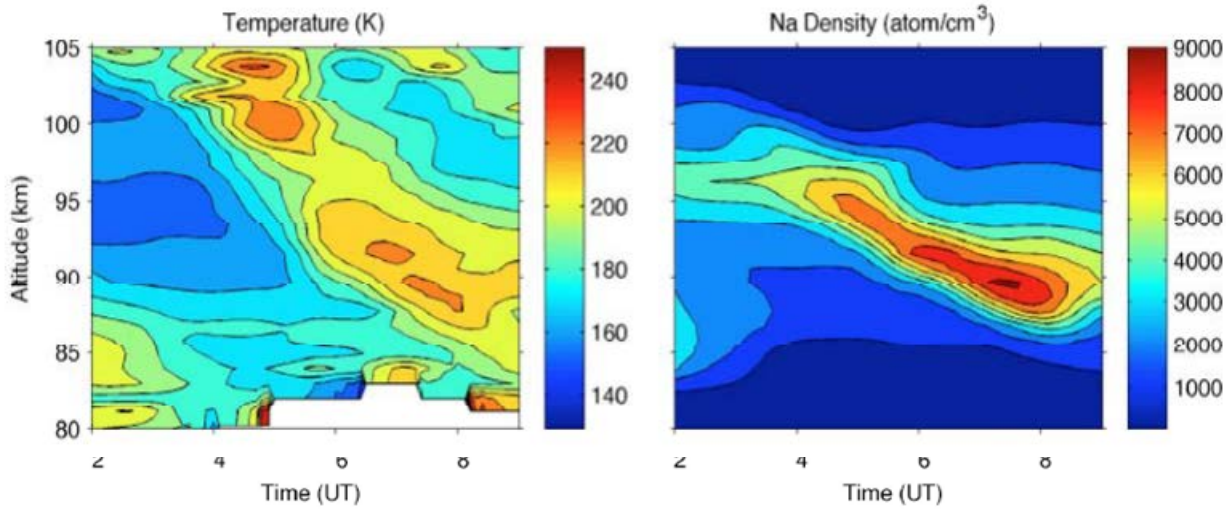
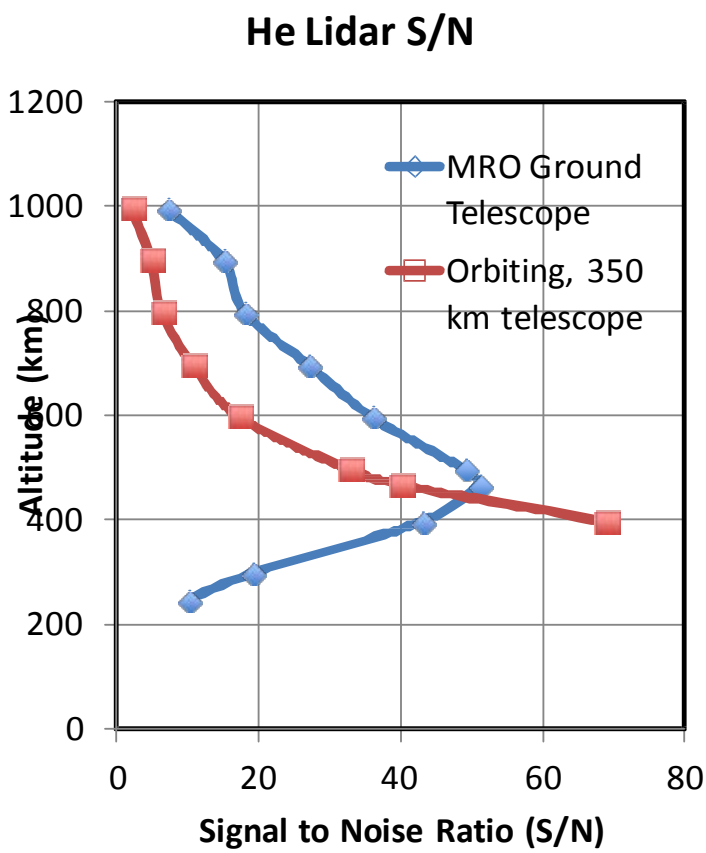


Figure 1. Example of measurements returned by ground-based lidar.

As with any measurement technique, ground-based lidar has limitations. True global coverage is required for to answer many important Heliophysics questions, but such coverage requires global deployment of a vast number of stations. This situation is obviously quite impractical, and is the reason that many measurement endeavors have been driven to space-based platforms. A second important limitation is the altitude range of utility. Returning measurements from above the lower thermosphere would provide new information on an important region of space that is not readily accessible for many measurement techniques. This whitepaper describes a paradigm by which significant progress can be made in both these areas by placing a lidar system in space.

The idea is to place a capable lidar system on the International Space Station (ISS). The system would utilize the new Large Aperture Optics assembly recently obtained by NASA as the collecting mirror for the return light. Thus nearly global coverage is obtained. Other aspects of the ISS are key to the operation of the system as well. The ISS can provide a long baseline (tens of meters) between the laser transmitter and the mirror collector to enable a CW bistatic system to be utilized in order that high signal-to-noise is obtained using current laser technology. Also, the laser requires significant power, and power is readily available on the ISS. The large focal plane of the optics assembly also offers the possibility of sharing the instrument among other uses, and the serviceability of an instrument on the ISS enables technology refresh capabilities.

The ISS also has significant payload capacity such that several laser systems could be utilized. For example, a standard sodium lidar paradigm could be used to probe the global mesosphere-lower thermosphere (MLT) from above as the ISS orbits. Other lidar targets could also be utilized to improve the vertical coverage. One example for extending the range higher into the thermosphere is the use of helium lidar. Such systems are beginning to show their utility on the ground, but in space they would have the advantage of being closer to their target. Fig. 2 contains the results of a simulation using a resonance at 1.084 microns for both the ISS case and the comparable ground-based case. The simulation parameters are given in Box 1, and it is clear that good performance up to 800 km is achieved for the orbiting instrument.



Box 1. Parameters for simulation results in Fig. 2.

Calculation for He is a CW beam, bistatic, with a baseline of 50 m between the transmitter and receiver.

Parameters: MRO—

Assumes dia=2.4 m telescope at Magdalena Ridge Observatory, Socorro, NM; 5 minute integration, height resolution=100 km, laser power=50 W

Orbiting at 350 km—Assumes dia=2.4 m telescope on ISS, 30 second integration (180 km horizontal resolution), height resolution=20 km, laser power=50 W

Figure 2. Results of helium lidar simulations, comparing performance for an instrument hosted on the ISS to that based on the ground. Simulation parameters are found in Box 1.

A third example is the use of Rayleigh lidar to extend the altitude coverage down into the mesosphere and stratosphere. Atmospheric dynamics in this region has been shown to be a significant driver of the behavior at higher altitudes of primary interest to Heliophysics, as pointed out in the 2012 Solar and Space Physics Decadal Survey. Fig. 3 shows a graphic presented at the Fall Meeting of the American Geophysical Union in 2006. It shows the performance of a Rayleigh lidar system utilizing a 1-m mirror orbiting at altitudes of 130 km and 250 km using a 10-W transmitter. The performance for the ISS-based system using a 2.4-m mirror has performance that is a factor of three less (although it could be compensated for by increasing the laser power).

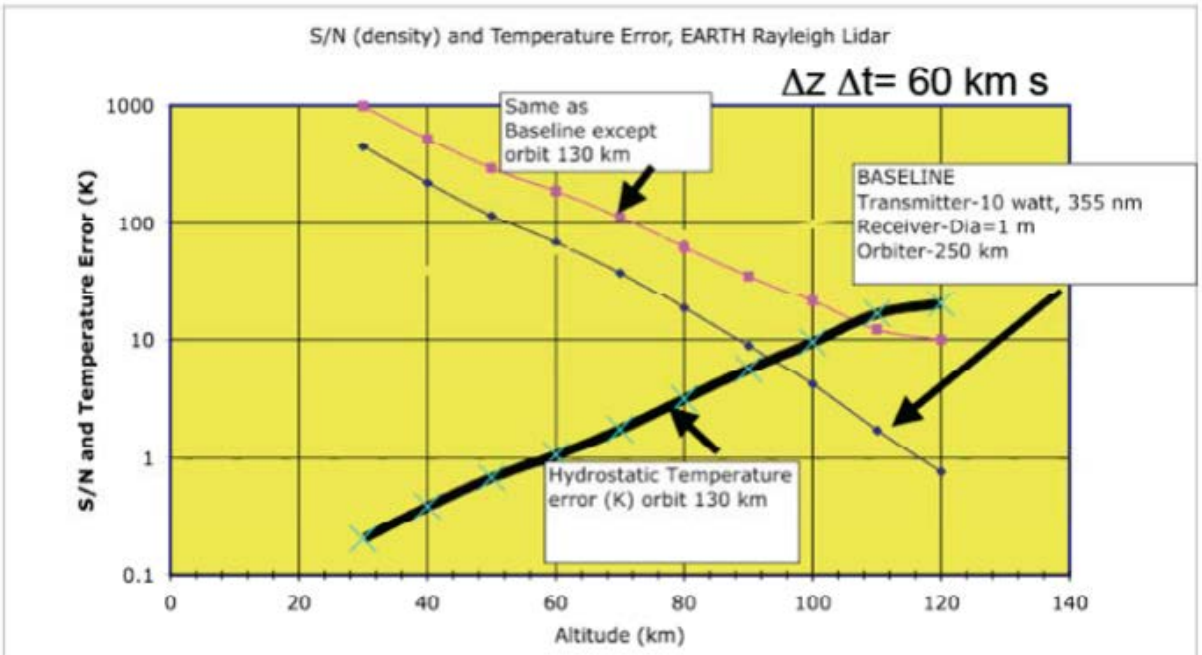


Figure 3. Simulated performance for Rayleigh lidar at two orbital altitudes using the parameters given.

Although three examples (sodium, helium, Rayleigh) have been given, other targets are also possible and should be explored with more resources than available for putting this whitepaper together. The next logical step for exploring this idea is to embark on a significant study. Key areas for study are:

- Identification of specific science targets in the upper atmosphere
- Trade study to identify the most promising and fruitful atmospheric targets
- Laser capability study
- Detector capability study
- Accommodation on and transportation to the ISS

While the case for this idea has been based most strongly on the need to make progress on Heliophysics science, a case can also be made for some elements of Earth science, as the Rayleigh lidar is sensitive below 60 km. Also, a good case can be made based on the societal relevance of this portion of the atmosphere, as all re-entering vehicles traverse this region, so having better situational awareness of the upper atmosphere would improve orbital and re-entry prediction accuracies.